Technical Memorandum

To: Paul Beaulieu, Trout Unlimited

From: Brian Graber, Staff Scientist, Massachusetts Riverways Program

CC: Todd Richards, Division of Fisheries & Wildlife

Terry Connolly, Trout Unlimited

Date: November 8, 2004

Re: Swift River Habitat Rehabilitation: Rock Structure Removal

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Background

This technical memorandum provides an assessment and conceptual recommendations for improving coldwater habitat in a stretch of the Swift River by eliminating a flow constriction caused by rock piles left in the river from a former bridge, and using that rock to augment riffle habitat upstream. The rock piles are a little less than 400 yards downstream of the Route 9 Bridge over the Swift River on the border of Ware and Belchertown, Massachusetts (see photo 1), located at coordinates 72°20'0.73"W and 42°16'22.82"N (see figure 1). The local Trout Unlimited chapter requested technical assistance from the Riverways Program to pursue habitat improvements related to the rock structure.

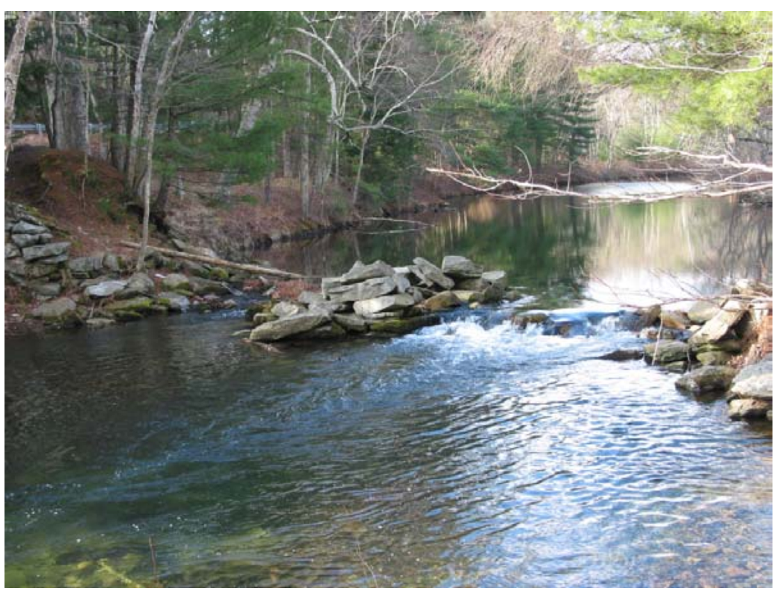

Photo 1. Rock structure constricting flow in the Swift River downstream of the Route 9 Bridge. Photo by Paul Beaulieu.

The drainage area at the rock structure is approximately 189 square miles, but this watershed size is hydrologically misleading because of the water withdrawals taken from the Quabbin Reservoir just upstream. The Winsor Dam on the Quabbin releases clean, cold water to the Swift River, which fluctuated between 53°F and 56°F during July and August field days in 2004. This release consistently maintains temperatures that are suitable for trout and the river is a popular site for anglers. The Division of Fisheries and Wildlife stocks this stretch and rainbow and brook trout were visible in significant numbers during fieldwork at the site. The visible rainbow trout population consisted of large adults, whereas brook trout were present in multiple age classes, indicating that brook trout spawn in the vicinity.

Figure 1. Topographic locater map of the rock structure.

Hydrologic Conditions

The hydrology of the Swift River in the vicinity of the proposed project is entirely regulated by the Winsor Dam upstream. The mean daily flow through the dam and into the Swift River from 1993-2002 was 107 cfs (flow data are from the immediately downstream USGS gauge #01175500). An additional 356 cfs mean daily flow is diverted from the Quabbin Reservoir for water supply throughout the Commonwealth. That is a magnitude of flow that once flowed in the river channel at the project site. The current channel carries less than a quarter of the previous mean daily flow.

Higher flows have also been significantly impacted. A graph of the largest flood peak of each year (Figure 2) shows an obvious change in flood flows following closure of the dam in 1939. The dam reduced the 100-year flood from 7,550 cfs from 1911-1939 to 2,970 from 1940-2002. Perhaps more significantly, in the 62 years since the dam was closed the flow has exceeded the previous 2-year flood level only three times, whereas before the dam, it would be expected to reach that level 31 times on average over that same time span. That is significant because river banks form at a level slightly below the two-year flood, so the current flow regime very rarely reaches levels that overtop the banks.

These changes in the flow regime are relevant because of their impact on the channel and on channel habitat features, described in the next section.

Over the ten years from 1993-2002, the flow fluctuated over the year from 56 cfs on average in November to 206 cfs on average in May. Field measurements for this work were taken when the flow was approximately 70 cfs, near the typical annual baseflow.

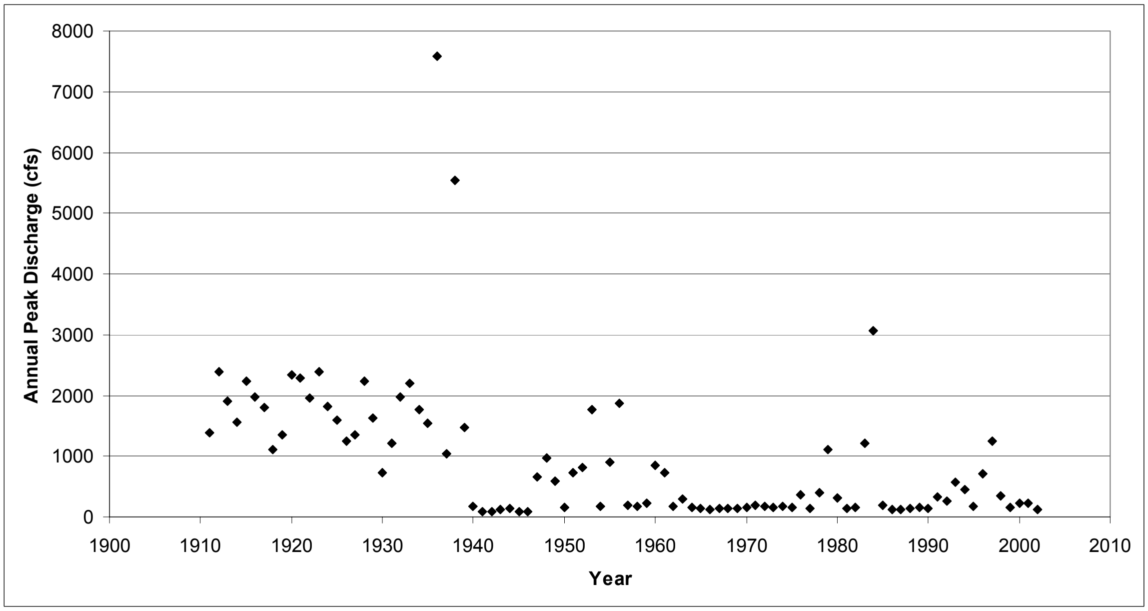

Figure 2. Graph of the largest peak flow of each year. Note the change after closure of the Winsor Dam in 1939.

Channel Conditions

There are two primary factors impacting habitat and habitat development in this stretch of the river:

- The rock structure is constricting flow, and is consequently impounding water and resulting in a long, flat pool.
- The river is flowing through a channel and over bed material sized for a previous flow and sediment regime.

Both of these factors are described below.

The river is currently a long pool for approximately 3,300 feet upstream of the rock structure and is completely devoid of riffle habitat. Riffles are important habitat features in this type of river because the shallower oxygenated flow through gravels on the bed are suitable for both spawning and macroinvertebrate productivity. Macroinvertebrates are an important food source for other aquatic life in the river.

Normally, pools form on the outside of bends in the river and riffles form in the straight portions in an alternating pool-riffle-pool pattern. As a very general rule of thumb, riffles are approximately found every five to seven river widths in this type of river, which translates to approximately every 400 to 600 feet in this stretch. So, a stretch of this length might normally have five or six riffles.

A longitudinal profile was surveyed to determine if bed features such as pools and riffles were covered by the impounded water and how the character of the river would change if the rock structure was lowered or removed (see Figure 3). The profile was measured on July 13, July 23, and August 11, 2004. A longitudinal profile is a survey of the water surface and the deepest part of the river bed along the river. For example, the point at the rock structure represents the lowest point of the structure's cross section. The flow in Figure 3 is moving from left to right. Note also the vertical exaggeration of the graph. Each of the bed features is longer than it appears on the graph.

Figure 3. A longitudinal profile showing elevations of the river bed and water surface. The river flow is from left to right. Note the vertical exaggeration – the bed features are longer than they appear on this graph.

Photo 2. A stretch of river upstream of the Route 9 Bridge showing the long, flat pool character of the river.

There are several features of note on the longitudinal profile:

- The water surface is remarkably flat upstream of the rock structure for 3,300 feet, with virtually no slope over that distance. This indicates the extremely low energy of this stretch of river.
- Note the drop in the water surface over the rock structure. This indicates that the rock structure is acting as a flow constriction and is impounding the flow by an additional depth of 0.8 feet.
- Fluctuations in the bed reveal bed features that are covered by the currently impounded water. If the water surface was lower, there might be riffles at distances 250, 1185, and 2695 along the profile.
- Note the riffle downstream of the rock structure beginning at distance 3425. This riffle is approximately 150 feet long and has characteristic shallower water with the water surface sloping downward as it drops in elevation along the riffle. This structure of flat pools and sloped riffles is characteristic of typical pool-riffle sequences found in rivers of this type. There is another similar riffle approximately 100 feet upstream of the upstream end of the longitudinal profile that was not measured.
- There is a deep pool just downstream of the Route 9 Bridge. This is a common feature downstream of bridges as the flow hydraulics through the bridge structure scour out the bed immediately downstream.

The current river channel is a remnant of a bigger river from before the Winsor Dam was constructed. In a more natural environment, with such a dramatic hydrologic change, the river channel would adjust over time by eroding and depositing sediment to form a smaller channel within the larger relict channel. However, over the 65 years since the dam was closed, relatively infrequent flood flows and almost complete lack of sediment give the river very little power or material to form a new channel and the habitat features that would result. As a result, the current channel is deeply incised, disconnected from the former floodplain, and mostly uniform in structure. In channel classification terms, what was a meandering, broad floodplain C channel is now an incised, uniform F channel.

Figure 4 shows a typical cross section measured between the bridge and the rock structure at river distance 2698 on the longitudinal profile. This cross section shows the steep, high banks and the lack of development of a new floodplain surface within the old river banks (see also Photo 3).

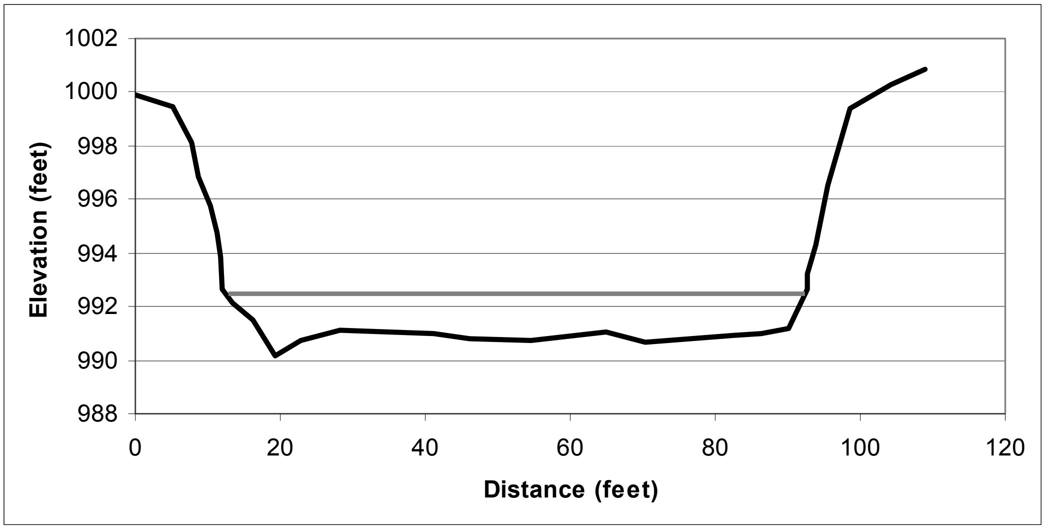

Figure 4. A typical channel cross section upstream of the rock structure showing the high, steep banks characteristic of this stretch. This cross section was surveyed at river distance 2698 on the longitudinal profile. The gray line is the water surface.

Photo 3. Surveying a cross section of the river upstream of the Route 9 Bridge. Note the flat, former floodplain surface more than six feet above the baseflow water surface.

Flow data from 1911-1939 indicate that the previous channel-forming or bankfull flow (slightly less than the 2-year flood) was approximately 1,500 cfs. In relatively natural conditions, channels form and river floodplains begin at the bankfull surface. This flow regime resulted in a bankfull channel cross sectional area of slightly more than 700 square feet. Under the flow regime since the dam closed, the bankfull flow is now approximately 200 cfs. A simple flow calculation using Manning's equation computes a bankfull cross sectional area of approximately 270 square feet for the current flow regime. This estimate is strengthened by field indicators of bankfull in the riffle downstream of the rock structure that are occurring at a cross sectional area of 280 square feet. In other words, the current channel size, which formed under a pre-Quabbin flow regime, has a cross section area of 707 square feet. The current flow regime would have formed a channel of 270 square feet. The river will shape itself over time to have a new channel within the current channel with a bankfull cross sectional area closer to 270 square feet, but that is occurring very slowly because of the extremely low energy and lack of sediment.

Some of the geomorphic process of channel adjustment and formation is beginning to be evident upstream of the bridge where deep pools alternate from river left to river right and back, forming the start of a smaller meandering channel within the current oversized banks. If more sediment was present, point bars would begin to form on the banks opposite from the deep pools creating the bends of the meandering channel. Downstream of the rock structure is a decent analog of the process where the higher velocity flow over the downstream riffle is moving material and beginning to form point bars downstream of the riffle. This is resulting in more beneficial habitat complexity in this downstream reach. Table 1 compares the channel features of the bankfull channel upstream of the rock structure with the riffle downstream of the structure.

Reach	covered riffle upstream of rock structure	riffle downstream of rock structure
sinuosity	1.11	1.11
channel slope	.00001	.00001
bankfull width (ft.)	82.3	79.7
bankfull mean depth (ft.)	3.28	3.52
bankfull maximum depth (ft.)	4.18	4.46
bankfull width/depth ratio	25.1	22.7
bankfull cross-section area ($ft.^2$)	270.1	280.3
entrenchment ratio	1.1	2.2
bed material	gravel	cobble
classification	F4	C3

Table 1. Channel metrics comparison between the bankfull channel upstream of the rock structure (at distance 2698) and the riffle downstream of the structure (at distance 3410). The upstream section could form a riffle if the rock structure is lowered or removed. The classification refers to a Rosgen classification computed from the above data. An F channel is a wide, shallow, and incised channel with little access to the former floodplain. A C channel has a broader and accessible floodplain. The '4' refers to the gravel substrate and the '3' refers to cobble.

A sample of the bed material approximately 500 feet upstream from the rock structure indicates that there is a solid bed underneath a small quantity of silt (see Figure 5). The longitudinal profile indicates that this portion of the stream may have been a riffle prior to the rock structure. Currently this section includes primarily gravels and cobbles along with the surficial silt. Swifter flowing water could clear out some of the silt material and expose more of a cobble bed, such as in the riffle downstream of the rock structure. Note in Figure 5 that the swifter flow in the downstream riffle creates a tighter distribution of particle sizes and smaller silt particles are flushed away. Note also that along with the channel structure itself, the bed material in the downstream riffle is also sized for a larger river indicating that this is a remnant of the previous channel and flow regime. The cobbles in the riffle were transported and deposited over time by much larger flows than currently occur. The current flow regime would be more likely to transport and deposit smaller gravels.

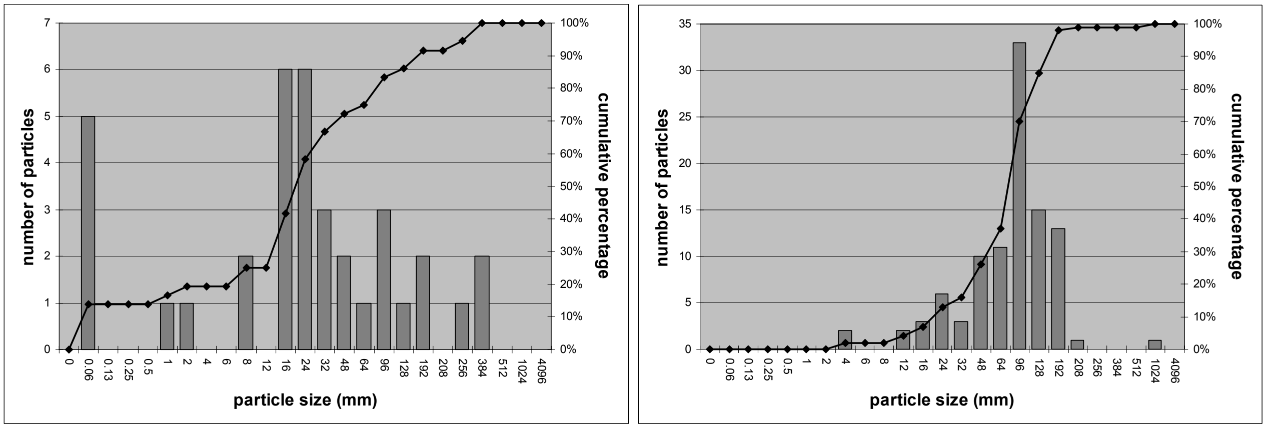

Figure 5. Bed material samples comparing the bed approximately 500 feet upstream of the rock riffle (left graph) with the bed in the riffle downstream of the rock structure (right graph). The left graph is a spread of gravel and cobble with some silt and the right graph is a tighter distribution centered around cobbles.

Recommendations

1) Lower the rock structure until the upstream water surface matches the downstream water surface. Lowering the rock structure will lower the water surface, increase the flow velocity, and beneficially expose some of the channel features between the rock structure and the riffle 3,400 feet upstream. The primary objective is to the lower the rock structure so that the water surface lowers the 0.8 feet that will connect it with the downstream water surface. Note that the flow depths in the downstream riffle range around one foot deep (see Figure 3). This indicates that when the water level is brought down by 0.8 feet, some extent of riffles will be uncovered where the flow depth will be near one foot deep. This will include features at river distances 250, 1185, and 2695 along the longitudinal profile (see Figure 6). This reduction in the water level will not significantly affect pool habitat as many deep pools will remain.

Note on the longitudinal profile that if the rock structure was completely removed, the downstream riffle would now control the upstream water level. The water level cannot go any lower than this downstream riffle. This is known as grade control, and the cobbles in the downstream riffle provide very stable grade control, meaning that the channel will not likely cut downward below that surface. As was mentioned earlier, the cobbles in the downstream riffle are sized from the previous flow regime. Based on an incipient motion analysis, the mean particle size in the downstream riffle will likely not move in a 100-year flood in the current flow regime. Therefore, the rock structure should not be lowered any further than 0.8 feet. Otherwise shallow, excessively high velocity flows will result in the downstream riffle that would not be beneficial.

Note that because the overall slope is so flat and because of the grade control downstream, the exposed riffles may not be extensive, but they will provide additional beneficial bed and flow complexity. In addition, if gravels and cobbles are uncovered by the swifter flow, they will provide surfaces for macroinvertebrates and therefore, more food sources for aquatic life in the river. Currently, cobbles in the downstream riffle contain more caddisfly casings than rocks upstream of the rock structure based on visual inspection.

Operationally, the current lowest point of the rock structure cross section should be lowered approximately 0.8 feet and the rest of the rock that is above this level should be removed while monitoring the change in the water surface.

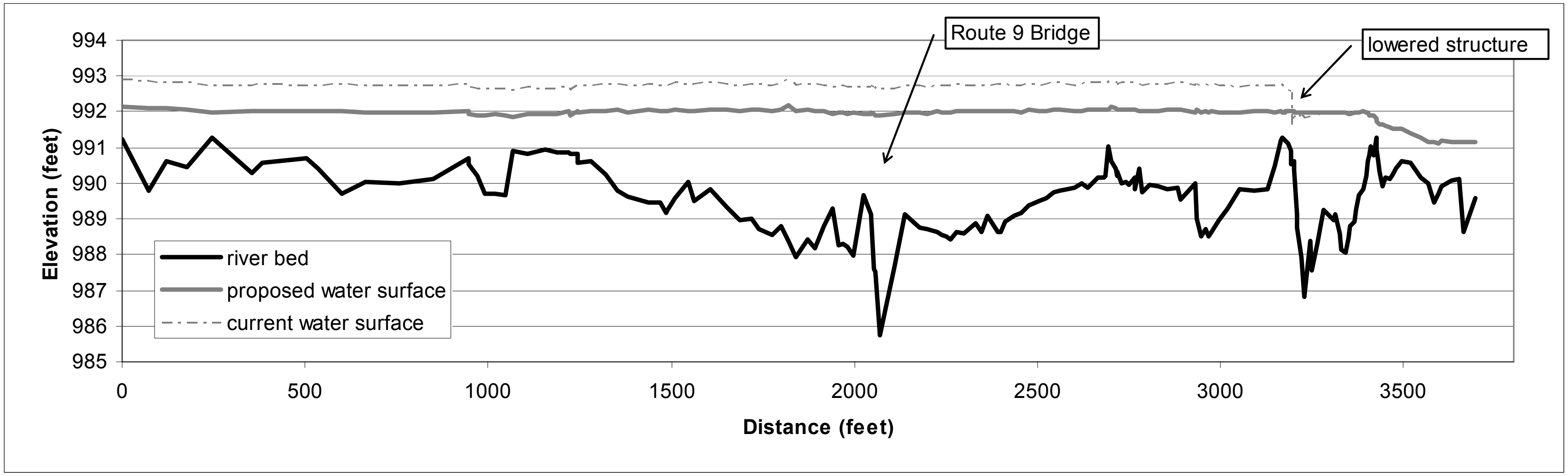

Figure 6. Longitudinal profile showing the proposed change in the water surface from lowering the rock structure. Note that the downstream riffle starting at distance 3425 will act as grade control after the rock structure is lowered.

2) Widen the cross section to the degree possible.
The river at the rock structure is narrower than elsewhere, additionally contributing to the flow constriction that is slowing flow upstream. Therefore, also remove the rock on the sides of the section to widen the cross section to the extent possible to eliminate it as a flow constriction. Figure 7 conceptually shows this by comparing the current rock structure cross section with the cross section of the downstream riffle. Again the ultimate objective is to lower the water surface by 0.8 feet and eliminating the flow constriction will help accomplish this.

Leave just enough rock to provide stability to the steep bank slopes. Alternatively, all the rock could be removed from the channel sides and bioengineering techniques could be used to stabilize the steep banks. The banks near the rock structure are steeper and higher than the surrounding banks upstream and downstream. Additionally, the banks could be pulled back to resemble the surrounding banks more. That approach would be significantly more expensive, but would result in more natural vegetated bank materials and more stable bank slopes.

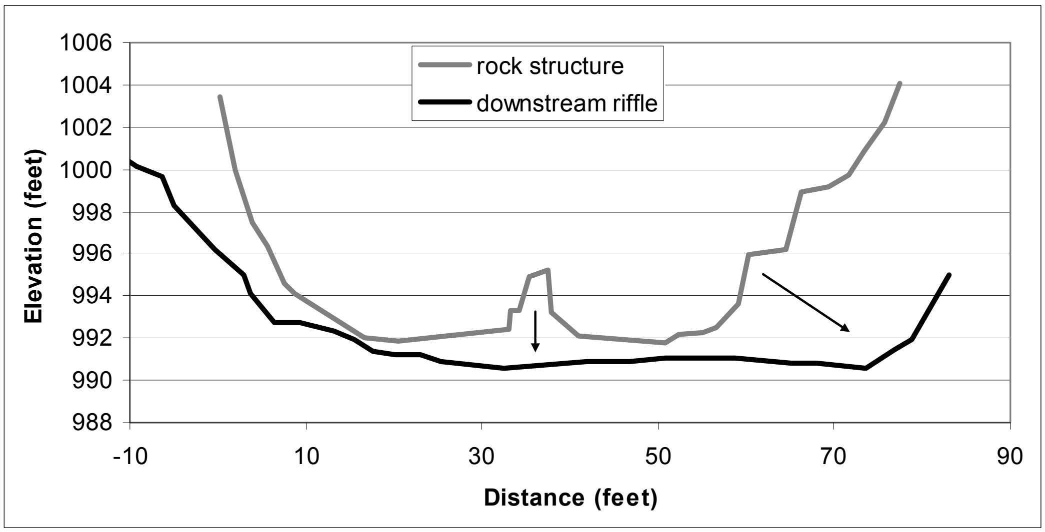

Figure 7. Conceptual comparison of the current rock structure cross section with the cross section of the downstream riffle. Rock should be removed from the rock structure to both lower and widen it. Note that the diagrams are showing the cross sections such that the right side is river right while facing in a downstream direction.

3) Use the removed rock to improve habitat.
Re-using the rock on site will serve the dual purpose of significantly reducing project costs by eliminating the need to carry away the rock, and will serve to provide additional habitat in the river.

As a first priority, use the rock to turn the current rock structure into a riffle. This should be accomplished by spreading the rock in an *upstream* direction from the current structure. By forming the riffle in the upstream direction, the pool-riffle spacing between this riffle and the downstream riffle will be more appropriate.

There are currently two ranges of rock sizes in the rock structure (see Photo 4). There are between 65 and 100 large rocks with median axis diameters of 1.7 to 2.9 feet. There are many smaller rocks surrounding these large ones with median axis diameters of 0.7 to 1.2 feet. All of these rocks are large relative to what would normally be found in a riffle in this flow regime, and therefore, they will provide a very stable bed surface. The rock sizes will be too large for optimal spawning sites, but spawning sites may be uncovered upstream when the water surface is lowered. Because of the large rock sizes, the created riffle will be immobile and should be periodically monitored to ensure that any channel changes such as downcutting do not result in the remaining rock obstructing flow again. Alternatively, if the means are available, the rock could be broken to smaller sizes on site.

Ideally, the surface of the riffle should be composed of the smaller rock sizes from the rock structure. This is because larger rocks near the water surface typically scour away smaller particles behind them because of the flow hydraulics, and this scour is undesirable in a riffle. The smaller rock sizes will fit together better to reduce these flow hydraulics and scour. Therefore, a layer of the larger rock can be used to partially fill the pool upstream and then the smaller rock can be spread over these. The elevation of the resulting riffle should not exceed the level 0.8 feet lower than the lowest point of the current rock structure cross section. This riffle can extend as far back as the downstream end of the pool at distance 3050 on the profile.

Photo 4. A close up photo of the rock structure shows the different rock sizes.

After constructing the riffle, if there is additional rock, it can be used to augment the riffle that will be uncovered at river distance 2700. Again, because of the scour, large rocks should either be put into deeper holes in the riffle or should be used at the downstream end of the riffle where they will only result in scour in the pool downstream.

Additional potential uses for the larger rock:

- The larger rocks could be placed randomly on the bed to increase bed cover and complexity. Because they may cause scour, these should be placed sparingly within riffles.

- The larger rocks could be used to form structures similar to the wing deflectors that are currently upstream of the bridge. Note that wing deflectors will narrow and deepen the river and therefore should only be used at pools and not in riffles. Ideally they should be installed on the opposite bank from the deepest part of the pool cross section. This will allow the deflectors to work with the natural formation of the channel.

- A cross vane, a U-shaped structure of rock that crosses the width of the river, could also be installed with the larger rock. Cross vanes narrow a short stretch of the stream and augment downstream pools by causing scour. Such a structure may be appropriate, but may also look unnatural in the stream. In addition, the first priority should be creating riffle habitat rather than pool habitat, because riffles are sorely lacking in this stretch of the river.

Additional Notes

- This technical memo was not written, designed, or reviewed by a licensed Professional Engineer.

- It is not likely that the upstream Route 9 Bridge will be adversely affected by the proposed work. A drop in the water surface of 0.8 feet should have a minimal impact particularly in light of the extremely gradual downstream slope of the river. Figure 6 shows the approximate expected change in the water surface, indicating that the flow will continue to be deep through the bridge section. Cross sections were surveyed at river distances 1219, 2046, 2165, 2546, 2697, and 3410 and could be used if a more elaborate hydraulic model is necessary. In addition, MassHighway is currently doing repair work on the bridge and should be consulted about the proposed project.

- If completing the proposed work with heavy machinery is infeasible or cost-prohibitive, it may be feasible to complete the work with draft horses. Such work has been accomplished elsewhere, such as by the USGS in northern Wisconsin (see Photo 5). A specialist would have to be consulted to determine feasibility. A local resident mentioned that there are horse pulling contests nearby, so there may be specialists in the vicinity.

Photo 5. Draft horses moving large rock at a stream restoration project in northern Wisconsin. USGS photo.

- The proposed work could be implemented more easily at low flow. A request could be made to the Winsor Dam operators (DCR Watershed Management) to hold back some of the flow during implementation.

- Because there is so little sediment and flow power in this stretch of the river, habitat could be enhanced by periodic increases of each. This may be possible by releasing sediment and periodic floods from the Winsor Dam and the reservoir upstream.

- Take care to space any underwater large rock so that it is safe to walk on or around. In other words, do not space large rock together such that a person could step in a crack between two boulders.

- Because the channel cross sectional dimensions are generally uniform and incised with high steep banks, there is very little vegetative cover or bed complexity to provide cover for aquatic species. The primary cover that is present is provided by somewhat sparse large woody habitat. This consists primarily of dead trees and branches that have fallen into the river. This important habitat should be left in the river.

- There is an additional deteriorating dam structure approximately 570 yards downstream of the rock structure that impounds water. Its removal could also improve coldwater habitat upstream of it. The structure does not appear in the state dams database. A local resident said that the structure is a former ice dam.

Photo 6. A deteriorating former ice dam 570 yards downstream of the rock structure.

Acknowledgements

Thank you to Terry Connolly of Trout Unlimited and Amy Singler of the Riverways Program for assisting with field measurements. Marty Melchior of Inter-Fluve, Inc. provided useful technical insights and conceptual ideas that were incorporated into the recommendations. Riverways Program staff Cindy Delpapa, Joan Kimball, and Amy Singler provided helpful substantive comments that were incorporated into this memorandum.